PROJECTS 1+2: physical and technical hydrology

INTRO AND SHORT NOTE

These two projects are designed to allow the student to deal with real scientific and engineering problems using real world data.
They are accompanied by two xls files :

Thornwaite.xls
Manning.xls

The first projects is within the scope of Physical Hydrology and aims at quantifying the **water balance of a catchment**. *Climate change* analysis can also be performed with the Thornwaite xls file.

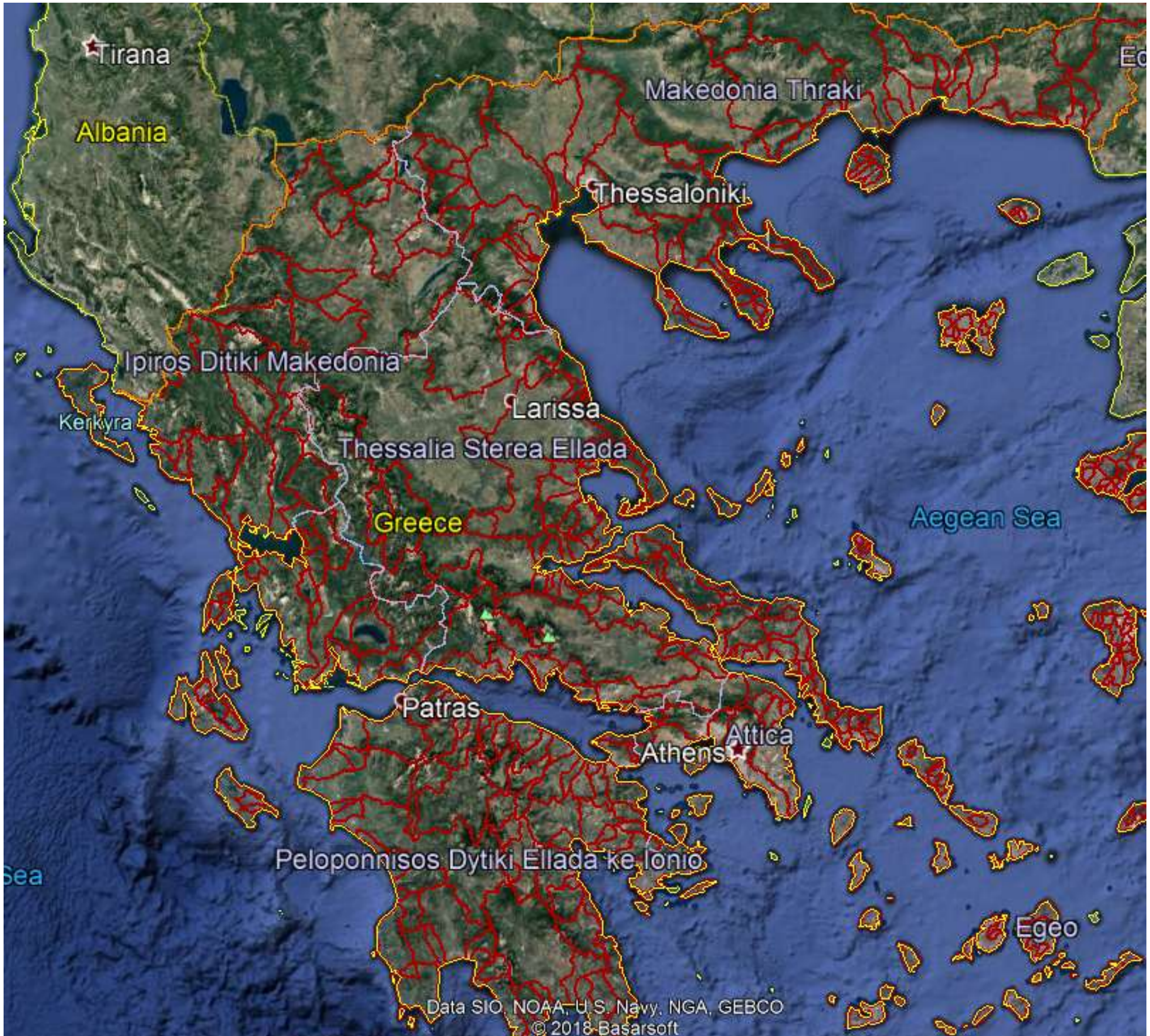
The second project lies in the area of *Technical Hydrology* and more particularly its purpose is, for the student to be able to calculate a **design discharge** for a specific catchment, in order to decide the **dimensions a hydraulic structure** (culvert) using the Manning xls file.

PROJECT 1: WATER BUDGET WITH THE THORNWAITE METHOD

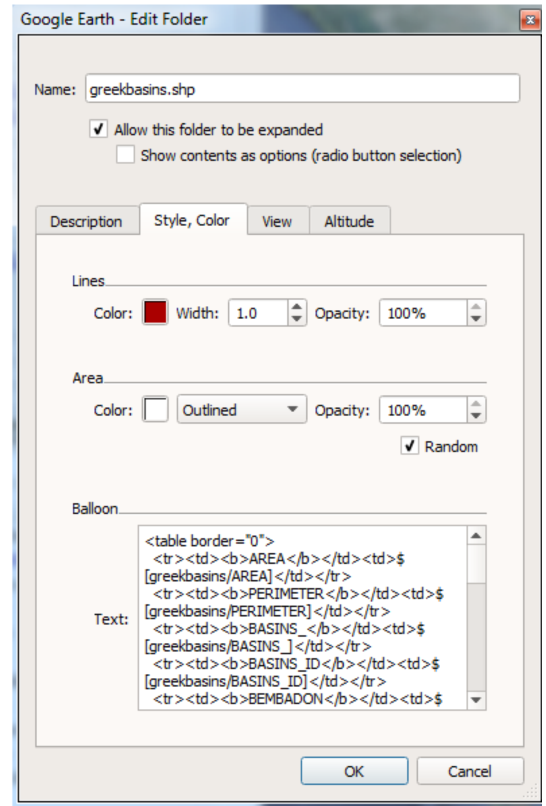
1. Choose a **catchment** in any region of any country(...)
2. You'll have to find a **meteorological station** within or near the catchment (for Greece search at http://climatlas.hnms.gr/sdi/)
3. Download average **monthly temperatures and rainfall heights**. We also need the **geographical coordinates φ,λ** and the **altitude (elevation) of the station**.
4. You'll check to see if you need to correct your data with the help of a **altitude – rainfall grading curve**. For this you need to search relevant publications and find references.
5. Construct **monthly water budget** with the use of the file Thornwaite Water Balance.xls
6. Make some more research and testing (climate change)
7. Structure and present your research accordingly (....)

Choose catchment

1. For Greece (...)



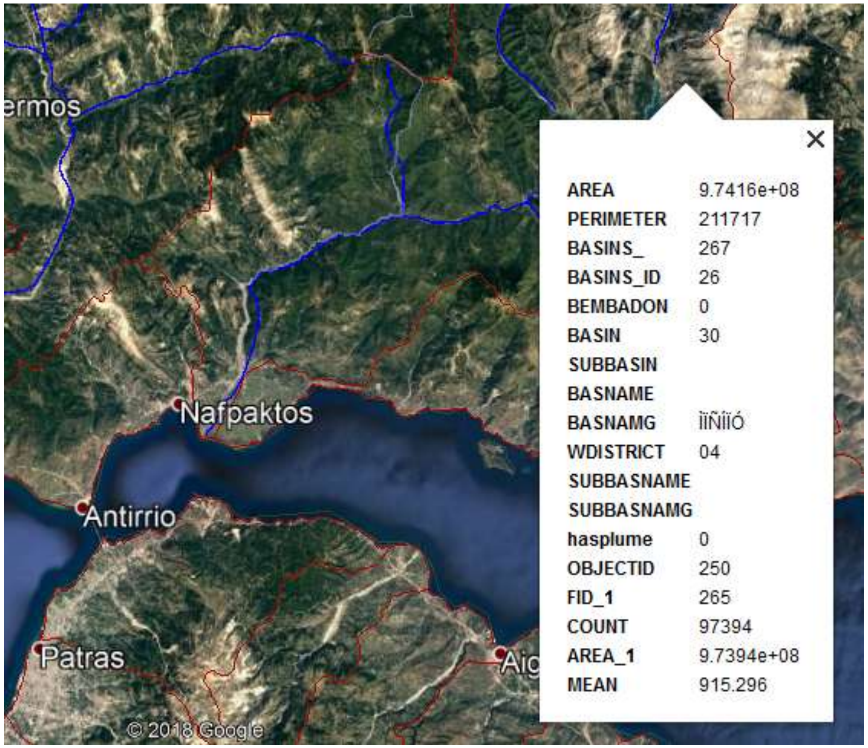
In Google Earth Pro
import greekbasins.shp
(+ greekrivers.shp)



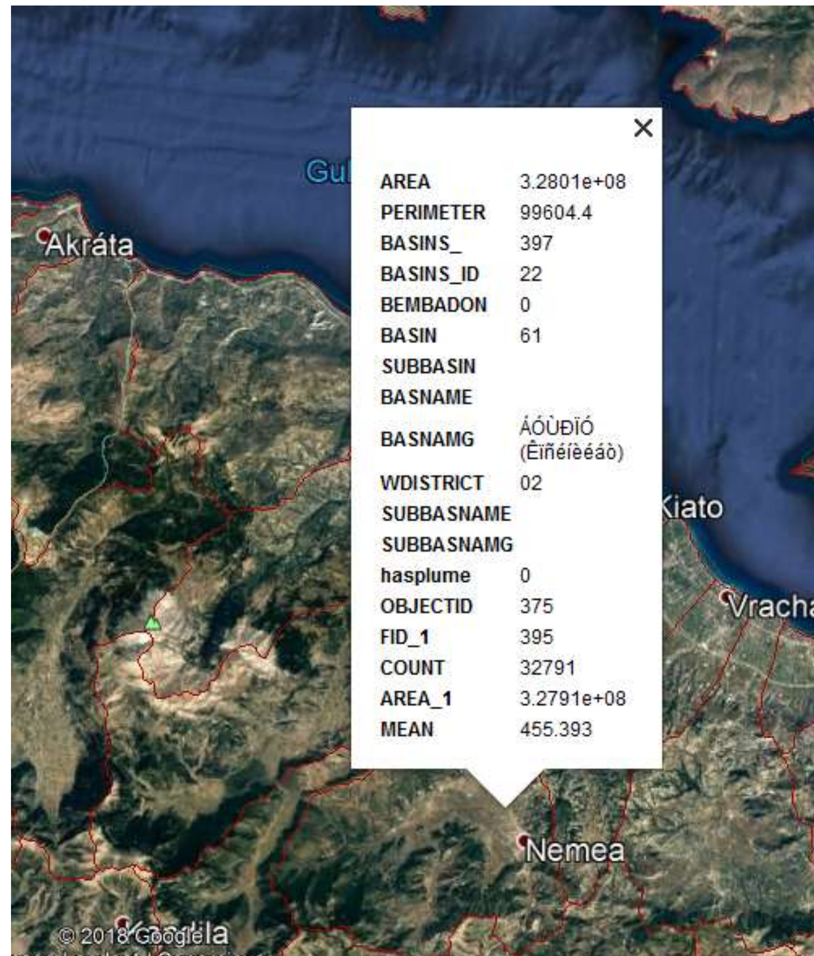
Choose a catchment..

check catchment's attributes

1. For Greece (...)



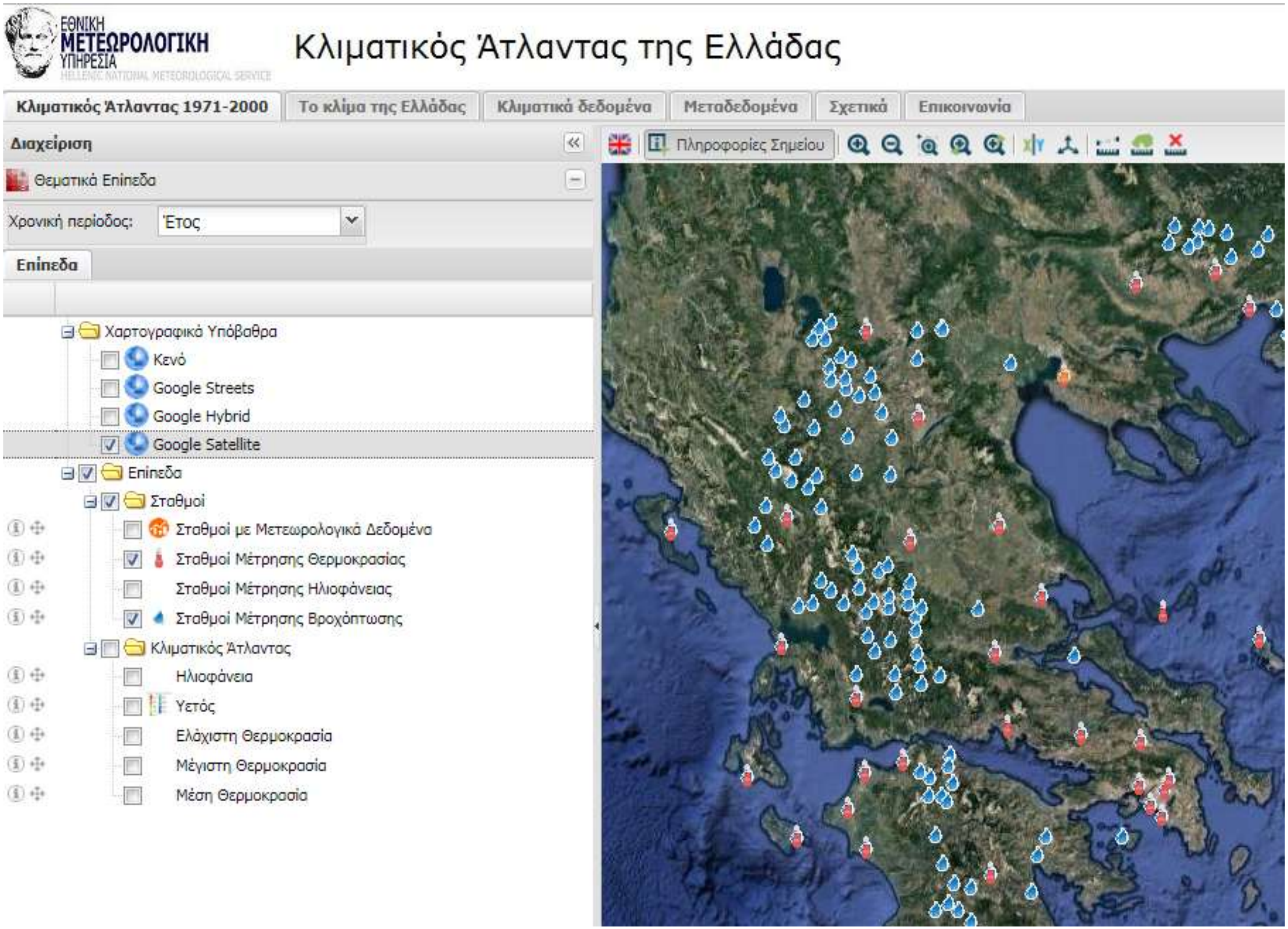
Press into a polygon and you'll get the polygon attribute table of the file.



From there you can find area (AREA in m²), perimeter in m, and its average elevation (MEAN in m)

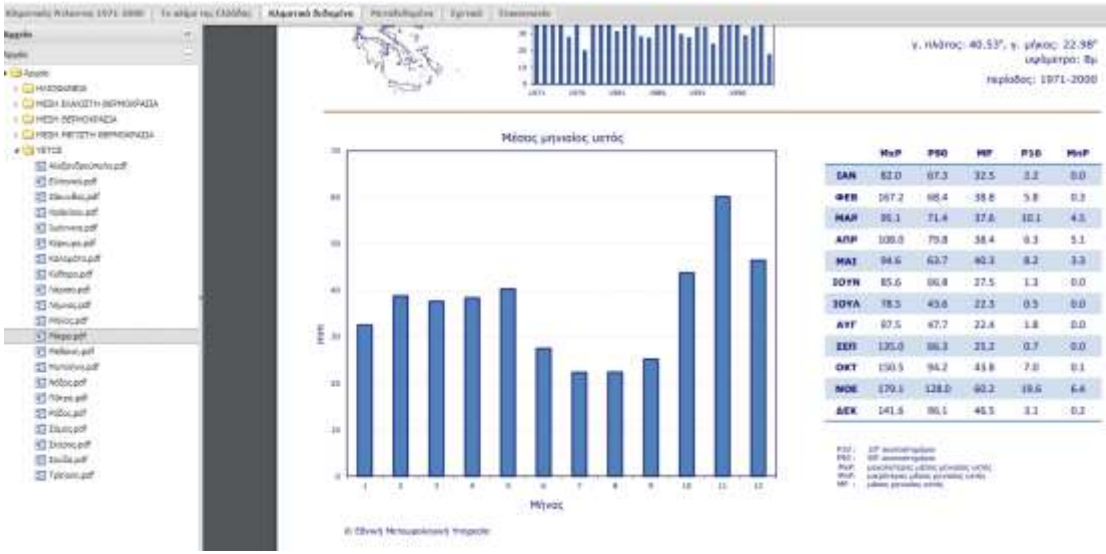
Find meteorological station

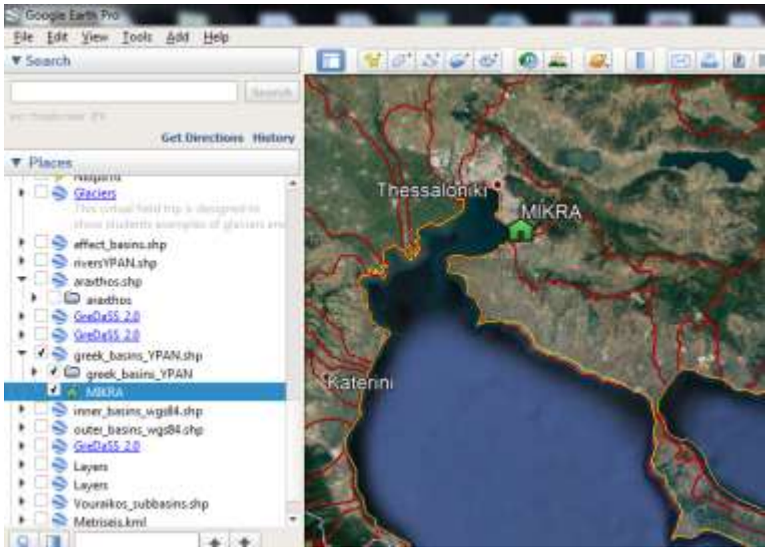
2. For Greece http://climatlas.hnms.gr/sdi/

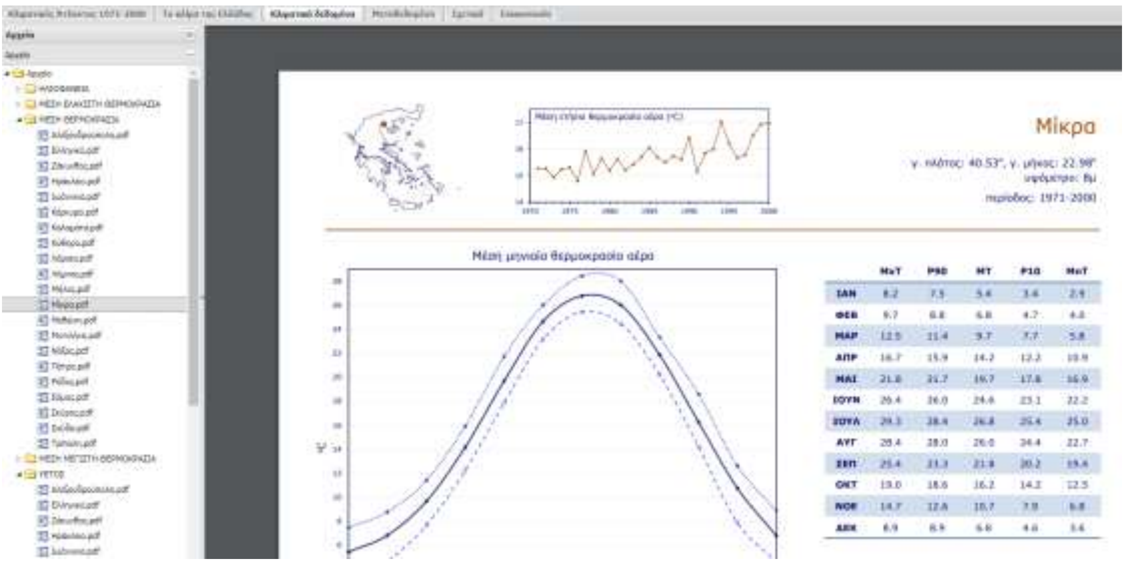


Download data from the meteo station

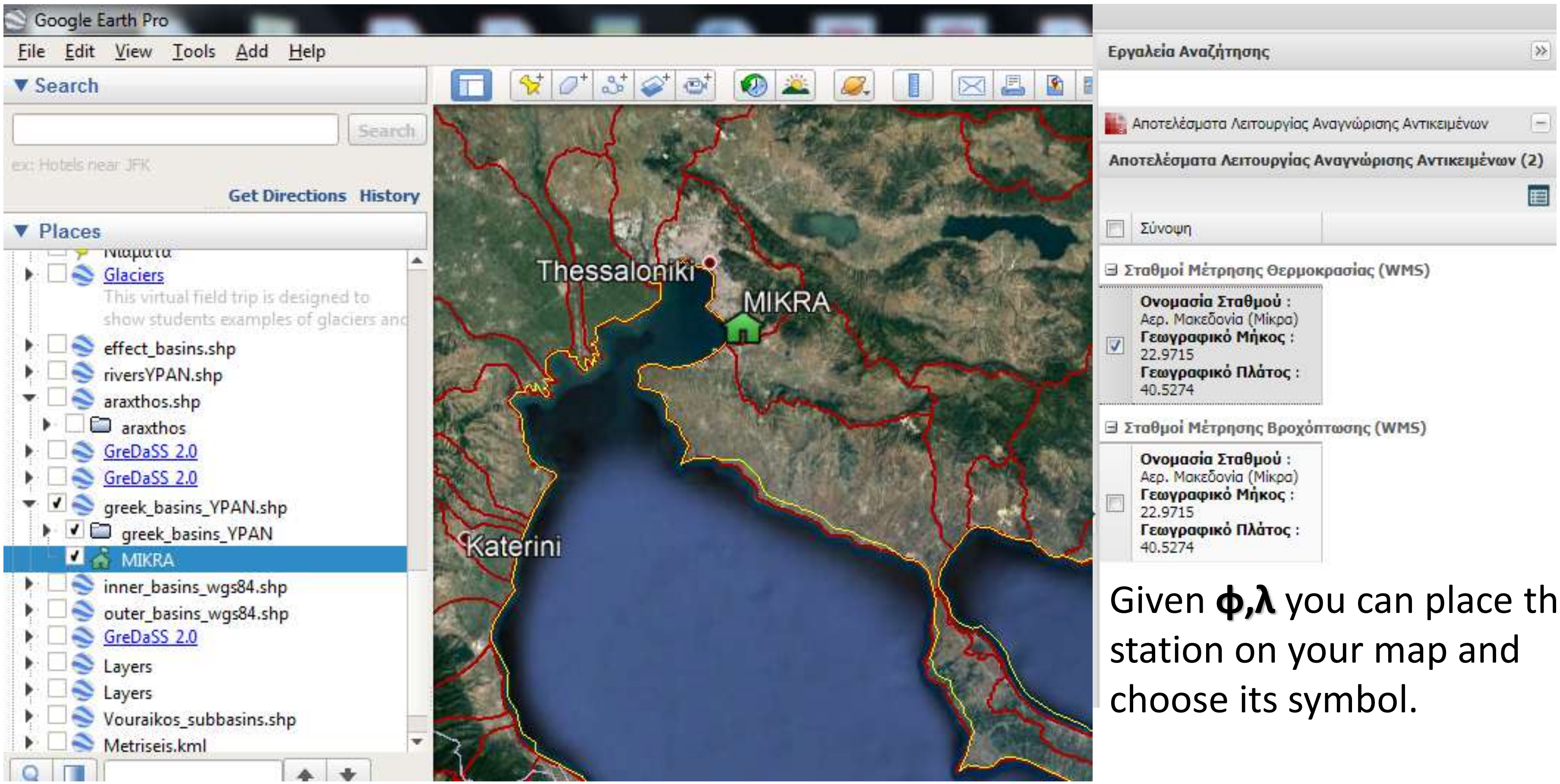
3. Monthly temperatures and rainfall for at least 30 years.







Download data from the meteo station

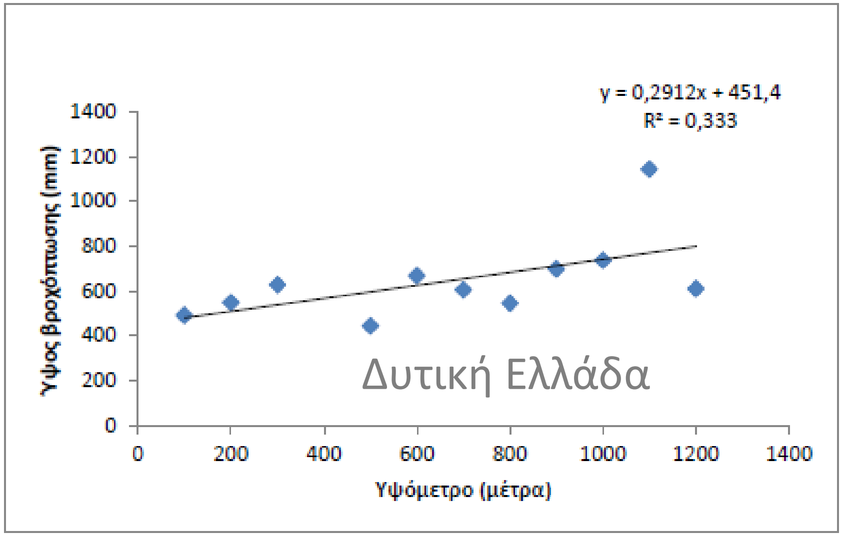


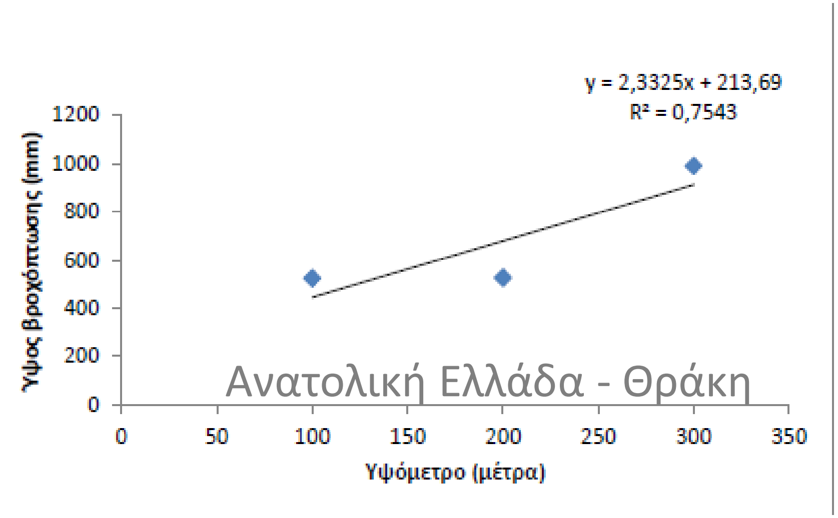
Given **φ,λ** you can place the station on your map and choose its symbol.

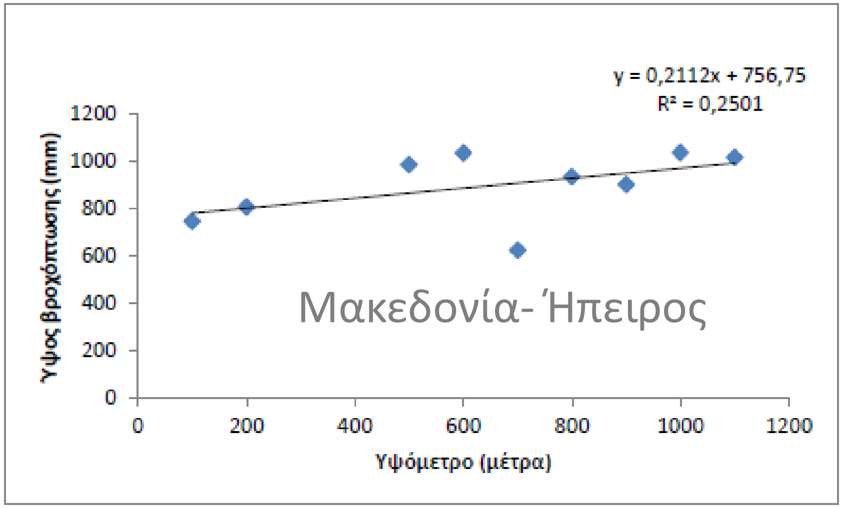
We also need the **geographical coordinates φ,λ** and the **altitude of the station**

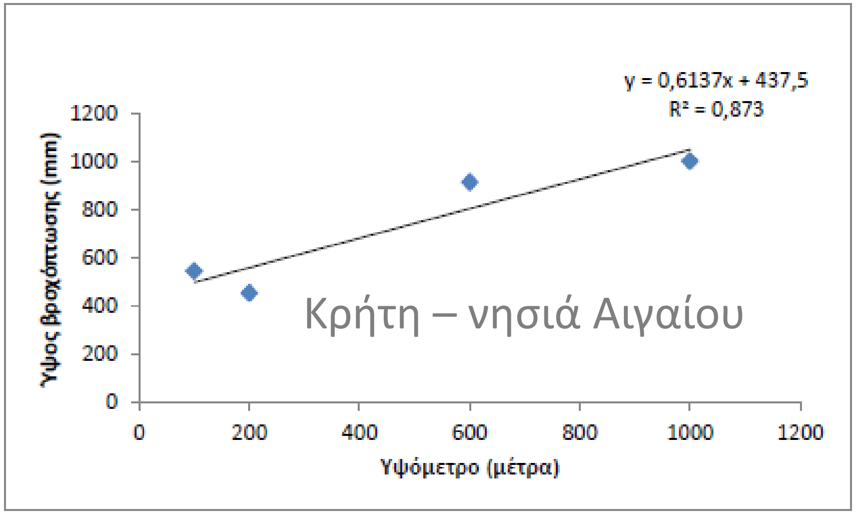
Correct rainfall for elevation if necessary

4. Check to see the difference between catchment's mean elevation and station's elevation. If they differ greatly (more, say, than ~300 m) you might have to look for a elevation – rainfall gradient curve from relevant publications. In any case check your final rainfall series for credibility.









WATER BALANCE CALCULATIONS

5. With the file Thornwaite Water Balance.xls

THORNTHWAITE-TYPE MONTHLY WATER-BALANCE MODEL

See Box 7-3. PET computed via Hamon equation [Eqn.(7-63)].

ThornEx.xls
S.L. Dingman
Physical Hydrology, 2nd Ed.

Input Data ϕ Computed Values

Location: **Omaha, NE** Lat. = **41.3** degree; 0.72 rad *SOILmax* = **100** mm

	J	F	M	A	M	J	J	A	S	O	N	D
Declination (deg)	-21.3	-13.3	-2.0	9.8	18.9	23.3	21.3	13.7	3.0	-9.0	-18.6	-23.3
Declination (rad)	-0.37	-0.23	-0.03	0.17	0.33	0.41	0.37	0.24	0.05	-0.16	-0.32	-0.41
DayLength (hr)*	9.3	10.4	11.8	13.2	14.3	15.0	14.7	13.6	12.4	10.9	9.7	9.0

*For lat. > 66.5, replace #NUM! with 24 in summer; 0 in winter.

WATER BALANCE

Temperatures in C, water-balance terms in mm.

Month:	J	F	M	A	M	J	J	A	S	O	N	D	Year
P	21	24	37	65	88	115	86	101	67	44	32	20	700
T	-5.4	-3.1	2.7	10.9	17.2	22.8	25.8	24.6	19.4	13.2	3.8	-2.1	
F	0.00	0.00	0.45	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.63	0.00	
RAIN	0	0	17	65	88	115	86	101	67	44	20	0	603
SNOW	21	24	20	0	0	0	0	0	0	0	12	20	97
PACK	45	69	49	0	0	0	0	0	0	0	4	24	
MELT	0	0	40	49	0	0	0	0	0	0	7	0	97
W	0	0	57	114	88	115	86	101	67	44	28	0	700
PET	0	0	29	56	90	130	151	131	88	54	26	0	755
W - PET	0	0	28	58	-2	-15	-65	-30	-21	-10	2	0	
SOIL	26	26	53	100	98	85	44	33	26	24	26	26	
ΔSOIL	0	0	28	47	-2	-14	-40	-12	-6	-2	2	0	
ET	0	0	29	56	90	129	126	113	73	46	26	0	688
W-ET-ΔSOIL	0	0	0	12	0	0	0	0	0	0	0	0	12

Graph | GraphData | ThornEx

Remember to change ϕ

Insert your data here in the brown yellow cells CC

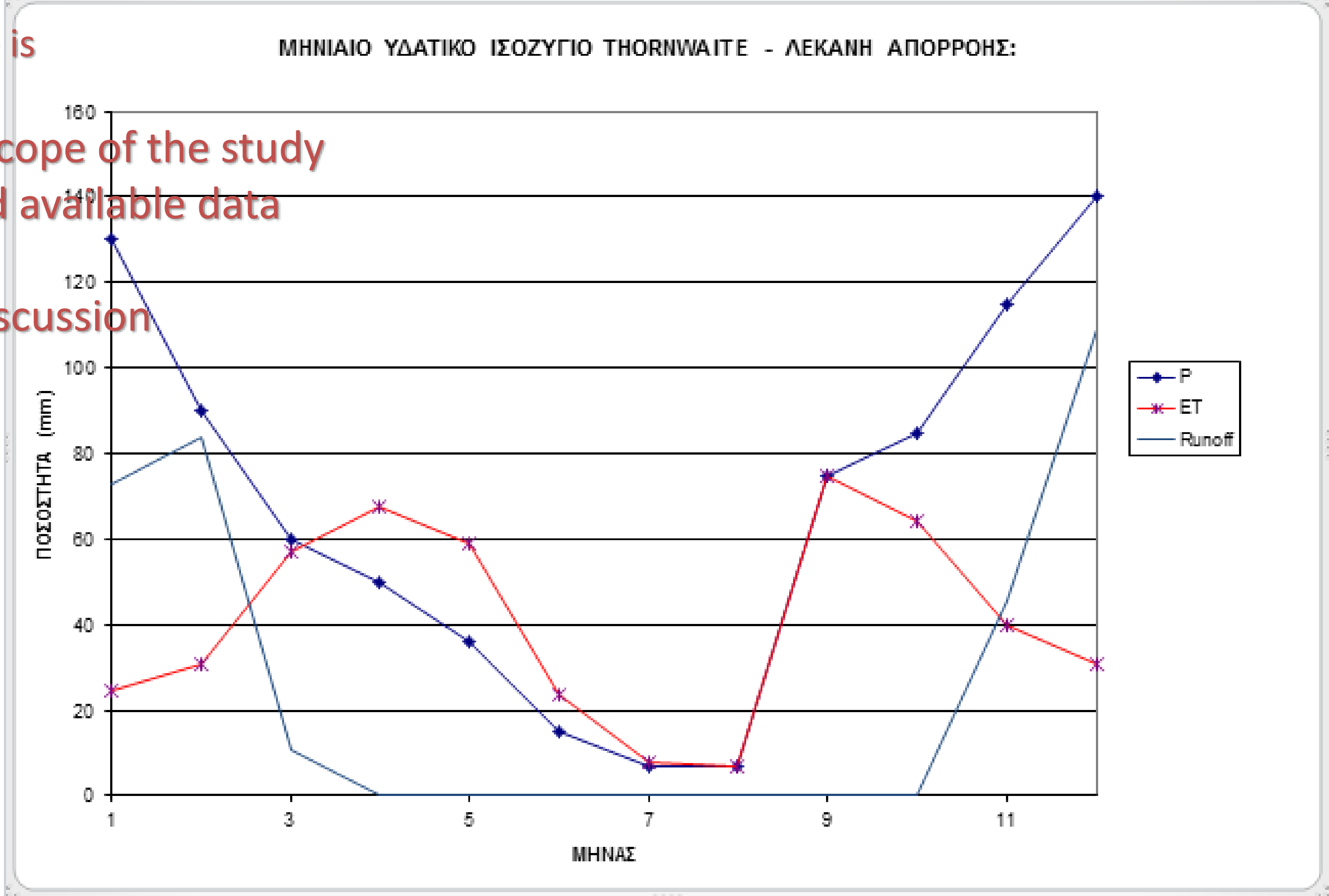
Results come as tables and graphs

RESULTS - PRESENTATION

6. Results come as tables and graphs such as the above.
7. Structure and present your study in a proper way.

A possible structure is

1. Purpose and Scope of the study
2. Study area and available data
3. Methods
4. Results and Discussion
5. References



FURTHER INVESTIGATION

6. YOU CAN INVESTIGATE FOR CLIMATE CHANGE.

For instance you can check your 30-years time series of temperature and rainfall to inspect for trends (or just compare the means of the three decades).

Then you can add to your temperatures (in the winter months) a couple of degrees, run again the xls and see what happens. This is for global warming. If there is a trend in rainfall depth then you can simulate that also.

Finally, you can test various values of SOIL MAX in the xls file. This is the maximum capacity the soil can retain and depends on local geology and other factors such as topography and physiography. For instance mountainous hilly valleys have shallow soils and low SOIL MAX while valleys in lesser slopy terrain can have thicker soils.

PROJECT 2: DIMENSIONING OF A HYDRAULIC STRUCTURE (CULVERT)

1. Choose a **catchment** in any region of any country, or take the one you used in the first project (...)
2. To complete the project you will need to find INTENSITY – DURATION – FREQUENCY (IDF) curves for your region.
3. In this project we use the RATIONAL method for the calculation of the design discharge and the MANNING formula to solve, and find the right dimension of the (rectangular) culvert. That is, height x width.
4. The design discharge will have to pass through the culvert allowing for a freeboard of 0.5 meters and with a velocity less than 5 m/s.

DESIGN DISCHARGE CALCULATION
THE RATIONAL METHOD

$$Q = C\, i\, F / 3.6$$

where:

Q discharge (m^3/s)

C runoff coefficient (dimensionless)

i rainfall intensity(mm/h)

F drainage area(km^2)

Limitations and assumptions in the Rational Method are as follows:

- The drainage area should not be larger than 200 acres.
- The peak flow is assumed to occur when the entire watershed is contributing runoff.
- The rainfall intensity is assumed to be uniform over a time duration equal to or greater than the time of concentration, T_c.
- The peak flow recurrence interval is assumed to be equal to the rainfall intensity recurrence interval. In other words, the 10-year rainfall intensity is assumed to produce the 10-year flood.

THE RATIONAL METHOD
Runoff coefficient

Table 1 Runoff Coefficients for the Rational Method

	FLAT	ROLLING	HILLY
Pavement & Roofs	**0.90**	**0.90**	**0.90**
Earth Shoulders	0.50	0.50	0.50
Drives & Walks	0.75	0.80	**0.85**
Gravel Pavement	**0.85**	**0.85**	**0.85**
City Business Areas	0.80	**0.85**	**0.85**
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay & Loam	0.50	0.55	0.60
Cultivated Land, Sand & Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	**0.90**
Parks & Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland & Forests	0.10	0.15	0.20
Meadows & Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

Note:

- ***Impervious surfaces in bold***
- *Rolling = ground slope between 2 percent to 10 percent*
- *Hilly = ground slope greater than 10 percent*

C depends mainly on

- Slope
- Vegetation / land cover

THE RATIONAL METHOD
Runoff coefficient

Table 1: General runoff coefficients for the rational method.

Description	Runoff Coefficient
Business	
Downtown Areas	0.70–0.95
Neighborhood Areas	0.50–0.70
Residential	
Single-family	0.30–0.50
Multi-family detached	0.40–0.60
Multi-family attached	0.60–0.75
Residential suburban	0.25–0.40
Apartments	0.50–0.70
Parks, cemetaries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yards	0.20–0.40
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Lawns; sandy soils	
Flat, 2% slopes	0.05–0.10
Average, 2%–7% slopes	0.10–0.15
Steep, 7% slopes	0.15–0.20
Lawns; heavy soils	
Flat, 2% slopes	0.13–0.17
Average, 2%–7% slopes	0.18–0.22
Steep, 7% slopes	0.25–0.35

C depends mainly on

- Slope
- Vegetation / land cover

THE RATIONAL METHOD
Rainfall intensity –IDF curves

4. Storm Intensity

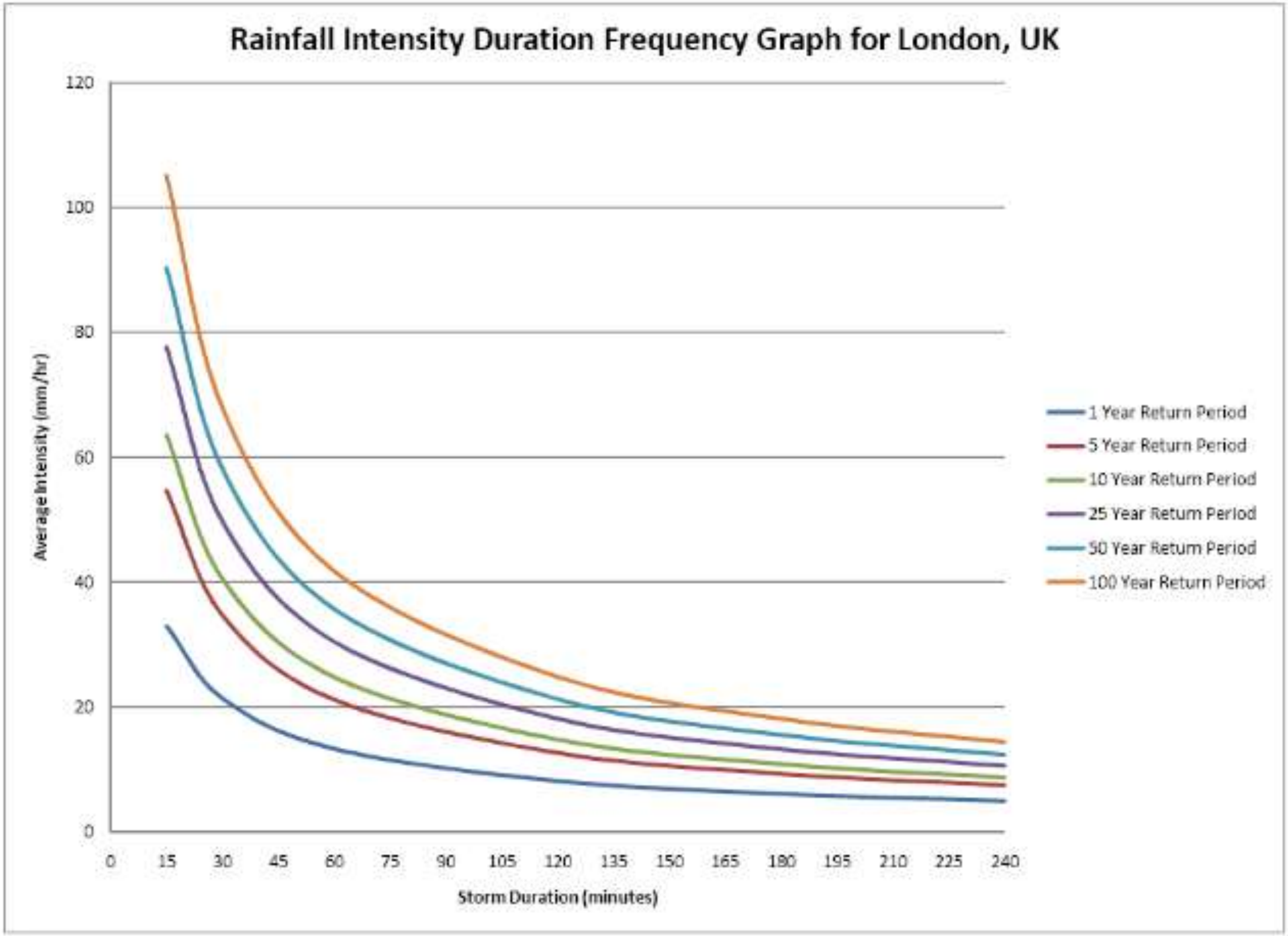
Storm intensity, i, is a function of geographic location and design exceedence frequency (or return interval). It is true that the longer the return interval (hence, the lower the exceedence frequency), the greater the precipitation intensity for a given storm duration. Furthermore, the longer the length of the storm, the lower the storm average precipitation intensity.

The relation between these three components, storm duration, storm intensity, and storm return interval, is represented by a family of curves called the *intensity-duration-frequency* curves, or IDF curves. The IDF curves can be determined by analysis of storms for a particular site or by the use of standard meteorological atlases, such as TP-40 (1963) and HYDRO-35 (1977).

For IDF curves, TxDOT[4] uses a formula for approximating the intensity-duration-frequency curve. The formula is

$$i = \frac{b}{(t_c + d)^e}, \tag{3}$$

THE RATIONAL METHOD
Rainfall intensity –IDF curves



THE RATIONAL METHOD
Rainfall intensity –IDF curves

General expression

$$i = \frac{cT^{m}}{(t+d)^{n}}$$

Where
i rainfall intensity(mm/h)
T return interval (years)
t time of concentration (hr)
c,d,m,n coefficients

Simpler expression

$$i = a / t^{b}$$

where a,b coefficients

Return interval	a	b
T=2	18,10	0,254
T=5	24,95	0,241
T=10	29,49	0,235
T=20	33,81	0,232

IDF coefficients for Milos Island, Greece

THE RATIONAL METHOD
Rainfall intensity –IDF curves

For IDF curves, TxDOT[4] uses a formula for approximating the intensity-duration-frequency curve. The formula is

$$i = \frac{b}{(t_c + d)^e}, \tag{3}$$

where:

$$i = \text{design rainfall intensity (in/hr)},$$
$$t_c = \text{time of concentration (min), and}$$
$$b, d, e = \text{parameters.}$$

For Lubbock County, the parameters are shown on table 2.

Table 2: IDF parameters for Lubbock County.

	Return Interval (years)					
Parameter	2	5	10	25	50	100
e	0.830	0.821	0.813	0.816	0.808	0.810
b	47	60	69	82	88	101
d	10.0	10.1	10.1	10.1	10.1	10.0

THE RATIONAL METHOD
Rainfall intensity – IDF curves – time of concentration

To calculate time of concentration t_c, that will be input in the IDF expression, we use various methods. The following is an empirical formula by Giandotti.

<u>Formula Giandotti</u>

$$t_c = \frac{4\sqrt{A} + 1.5L}{0.8\sqrt{Z}}$$

where

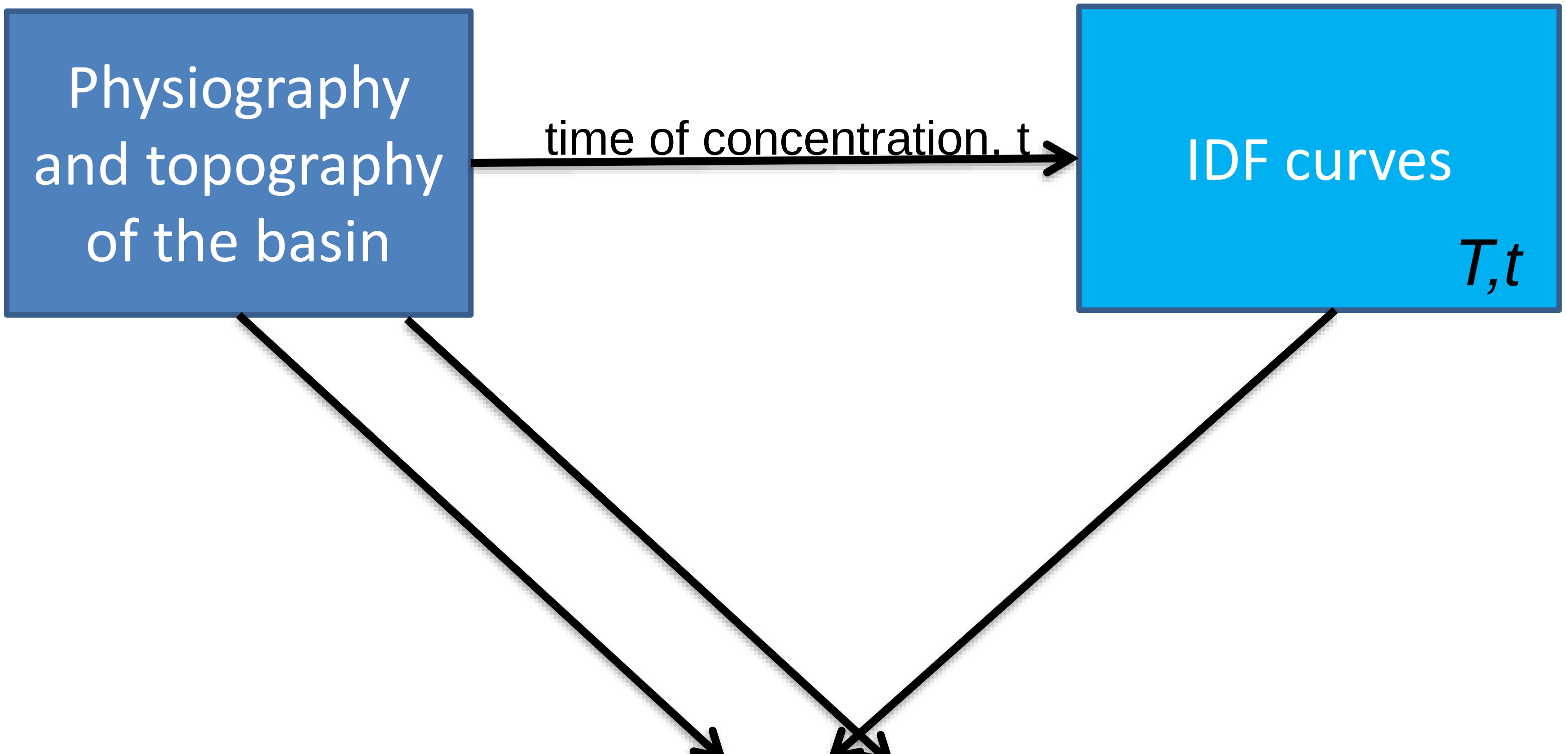
t_c time of concentration (hr)

A drainage area (km^2)

L length of the main stream (km)

Z difference between the average elevation of the basin and the elevation at the outlet (m)

THE RATIONAL METHOD
general view



$$Q = C\ i\ F\ /\ 3.6$$

project 2: dimensioning of hydraulic structures

In your basin a new road is constructed.

At some point the road's centerline meets the axis of a stream.

You will have to decide on the dimensions of a culvert that will accommodate the safe passage of the flood discharge of the stream under the road.

FIRST STEP: Find **T, the storm return interval**.
This depends on the significance (the category) of the road.
Else, take T=50 years.

Πίνακας 65. Περίοδοι επαναφοράς βροχόπτωσης μελέτης – Όρια κατάκλυσης οδοστρώματος οδικών έργων (ΟΜΟΕ)

Χαρακτηριστικά οδού	*Κατηγορία*	*Συχνότητα βροχόπτωσης, ανάλογα προς τα έργα (έτη)*			*Όρια κατάκλυσης από πλημμύρα*
		Οχετοί	*Έργα υδροσυλλογής συνδέσεων και τοπικών αγωγών*	*Κύριοι αγωγοί*	
Κυκλοφορούμενα τμήματα οδών, κλάδοι κόμβων και άλλα τμήματα ίδιας σημασίας	Αυτοκινητόδρομοι	50	10	50	Χωρίς κατάκλυση του οδοστρώματος
	Εθνικές & Επαρχιακές οδοί	50	10	25	Χωρίς κατάκλυση του οδοστρώματος
	Αστικές ελεύθερες λεωφόροι	—	10	50	Χωρίς κατάκλυση των λωρίδων κυκλοφορίας*
	Ταχείες λεωφόροι και άλλες αρτηριακές αστικές οδοί	—	10	25	Κατάκλυση το πολύ μέχρι το μισό πλάτος μιας λωρίδας κυκλοφορίας
Κυκλοφορούμενα τμήματα οδών και κλάδοι κόμβων και άλλα τμήματα ίδιας σημασίας σε βαθιά σημεία και σε ταπεινωμένα τμήματα που απαιτούν άντληση	Αυτοκινητόδρομοι	50	50	50	Χωρίς κατάκλυση του οδοστρώματος
	Εθνικές & Επαρχιακές οδοί	50	25	25	Χωρίς κατάκλυση του οδοστρώματος
	Αστικές ελεύθερες λεωφόροι	—	50	50	Χωρίς κατάκλυση των λωρίδων κυκλοφορίας*
	Ταχείες λεωφόροι και άλλες αρτηριακές αστικές οδοί	—	25	25	Κατάκλυση το πολύ μέχρι το μισό πλάτος μιας λωρίδας κυκλοφορίας
Δευτερεύον δίκτυο	Παράπλευρες οδοί και εγκάρσιες δευτερεύουσες αστικές οδοί – κοινοτικές και λοιπές δευτερεύουσες υπεραστικές οδοί	50	10	10	Κατάκλυση το πολύ μέχρι το μισό πλάτος μιας λωρίδας κυκλοφορίας

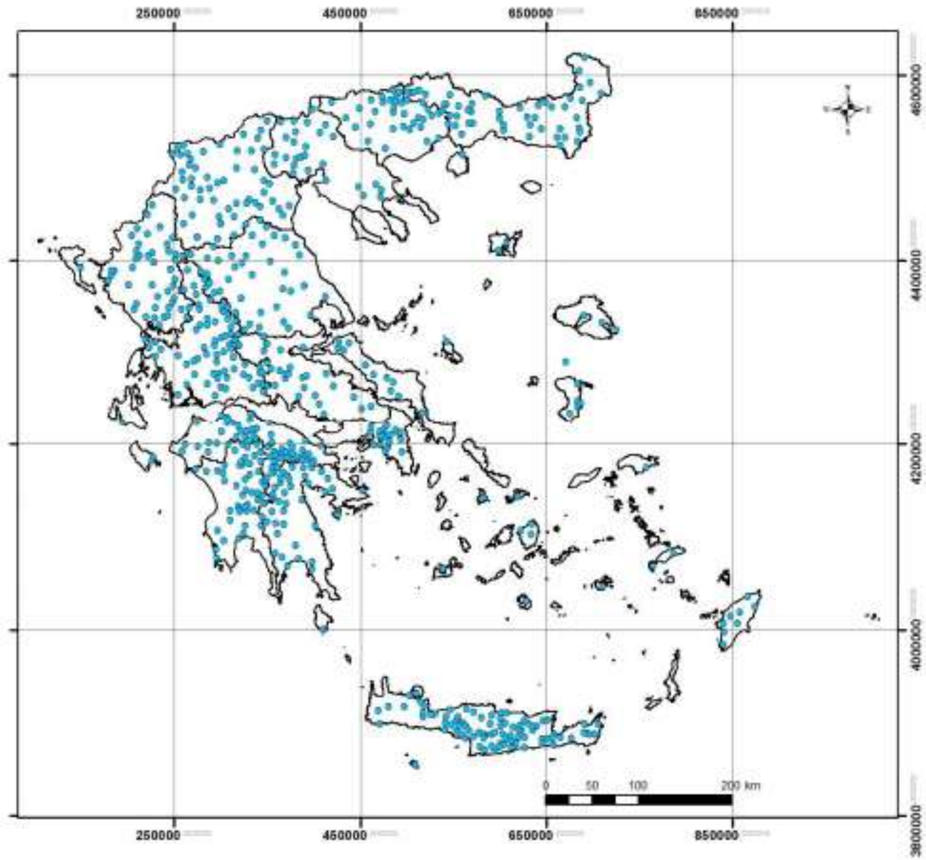
* Σε περιπτώσεις όπου δεν υπάρχει Λ.Ε.Α. στη θέση όπου γίνεται ο έλεγχος, τότε επιτρέπεται κατάκλυση της λωρίδας κυκλοφορίας σε πλάτος τόσο ώστε το μέγιστο ύψος νερού πλημμύρας στο άκρο της λωρίδας κυκλοφορίας να είναι το πολύ ίσο προς 0,02 m

FOR GREECE LOOK HERE
https://floods.ypeka.gr/index.php?option=com_content&view=article&id=174&Itemid=604

ΕΦΑΡΜΟΓΗ ΟΔΗΓΙΑΣ 2007/60/ΕΚ

ΚΑΤΑΡΤΙΣΗ ΟΜΒΡΙΩΝ ΚΑΜΠΥΛΩΝ ΣΕ ΕΠΙΠΕΔΟ ΧΩΡΑΣ

SECOND STEP: FIND THE **IDF CURVES** FOR THE REGION OF YOUR PROJECT



Αθήνα, Μάιος 2016

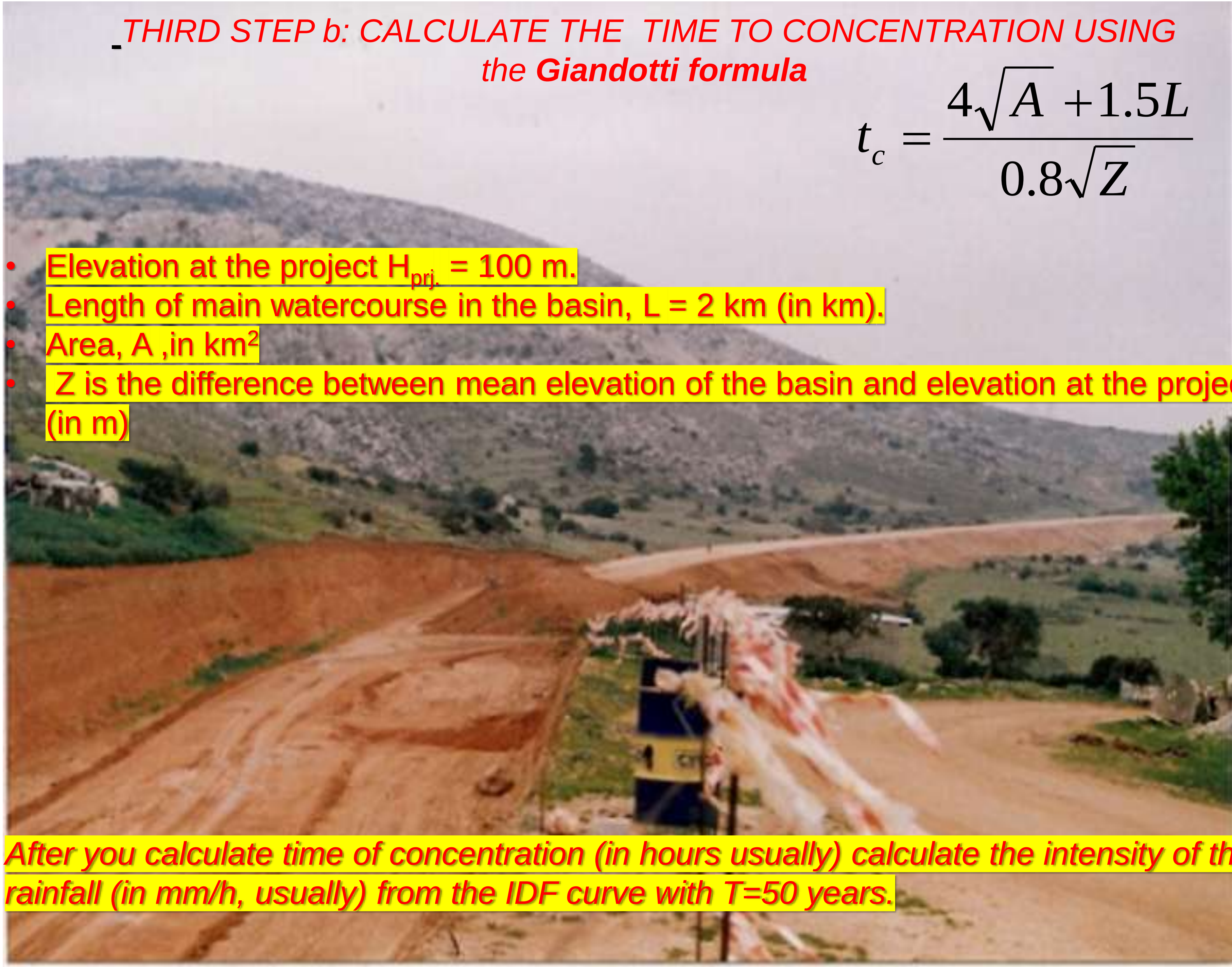
THIRD STEP a: decide on the RUNOFF coef. – C-

- Average slope 15 %.

- GIVEN THE PHYSIOGRAPHIC AND TOPOGRAPHICAL FEATURES OF YOUR CATCHMENT, DECIDE ON THE RUNOFF COEFFICIENT –C- THAT YOU ARE GOING TO USE.

-*THIRD STEP b: CALCULATE THE TIME TO CONCENTRATION USING the* ***Giandotti formula***

$$t_c = \frac{4\sqrt{A} + 1.5L}{0.8\sqrt{Z}}$$



- Elevation at the project $H_{prj.}$ = 100 m.
- Length of main watercourse in the basin, L = 2 km (in km).
- Area, A ,in km^2
- Z is the difference between mean elevation of the basin and elevation at the project (in m)

After you calculate time of concentration (in hours usually) calculate the intensity of the rainfall (in mm/h, usually) from the IDF curve with T=50 years.

THIRD STEP c: CALCULATE THE storm intensity –i-

- USE THE IDF CURVE WITH THE tc THAT YOU FOUND IN PREVIOUS STEP.

FOURTH STEP: CALCULATE **Q**

$$Q = C\,i\,F / 3.6 \quad \text{in } m^3/s$$

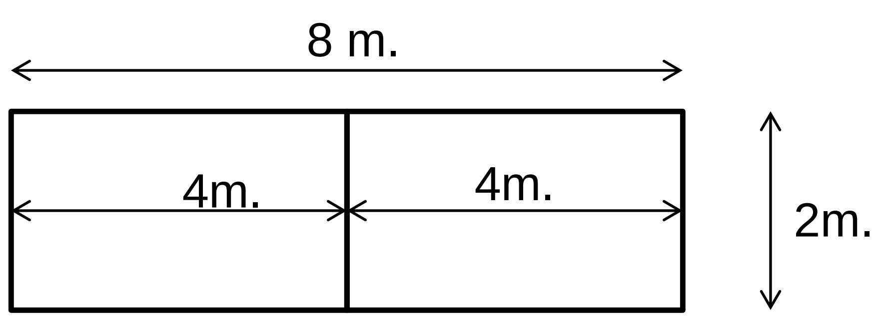
fifth STEP: given Q, decide on the dimension of the culvert

given:

Up to 3 meters of height. Longitudinal slope S = 0,5%. V not over 5 m/s and freeboard = 0.5 m. That means that the height of the water in the prism –y- should not be more than the height of the structure minus half meter .

USE $n_{Manning}$ = 0.015.

YOU HAVE TO USE THE AVAILABLE DIMENSION GIVEN IN TABLE 9.1-.1 next page.
If you need to use two rectangles side-by-side, for instance two 4x2 (height x width, υxβ), solve Manning with b = 8m.



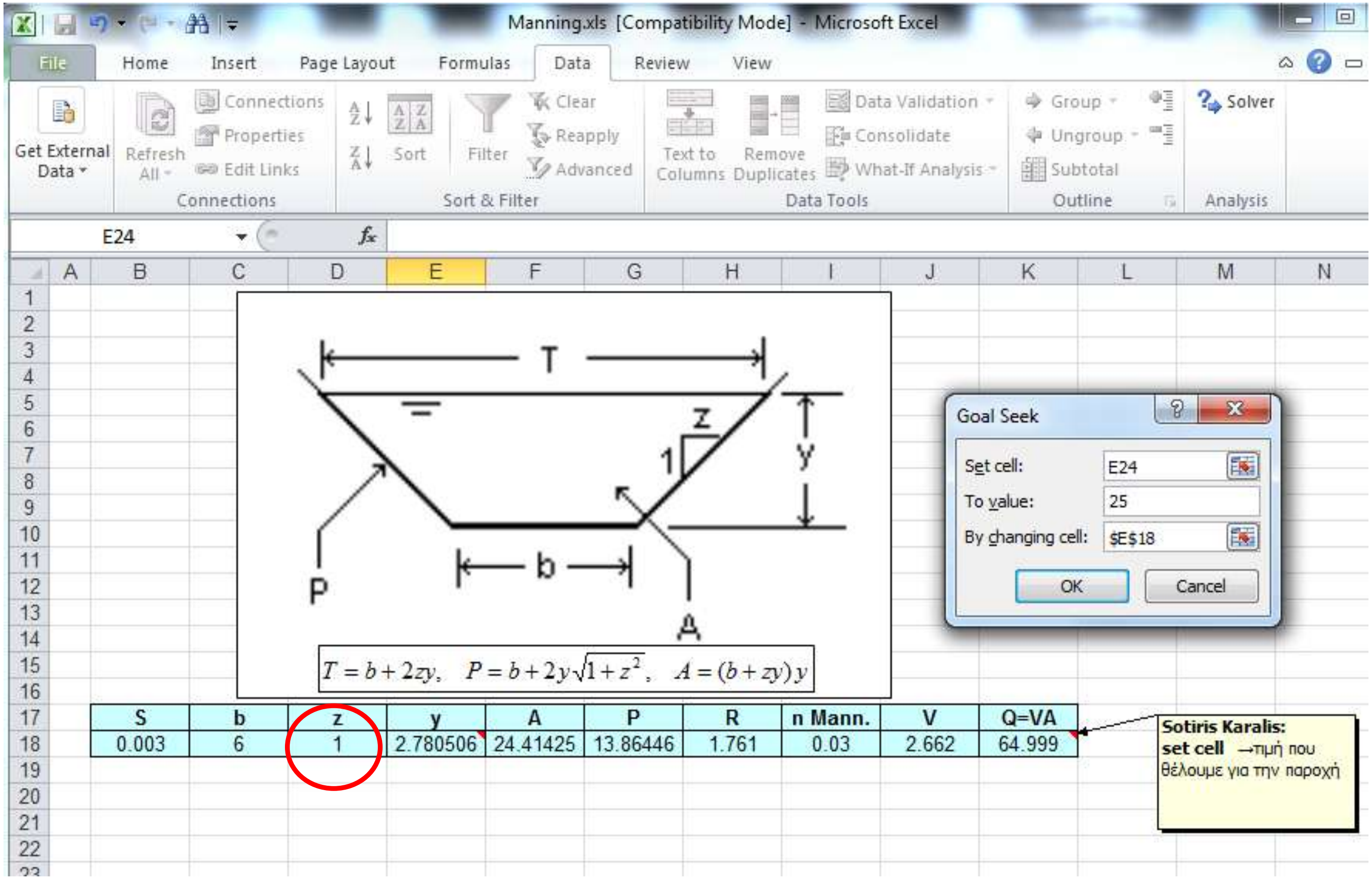
AVAILABLE ORTHOGONAL CULVERTS DIMENSIONS:TABLE 9.1-.1

Πίνακας 9.1-1: Τυποποιημένες διαστάσεις κιβωτοειδών οχετών (υxβ)

HEIGHT m.

	Άνοιγμα οχετού WIDTH m.					
Ελεύθερο ύψος οχετού	[m]	2,00	3,00	4,00	5,00	6,00
	4,00			4x4	4x5	4x6
	3,50			3,5x4	3,5x5	3,5x6
	3,00		3x3	3x4	3x5	3x6
	2,50		2,5x3	2,5x4	2,5x5	2,5x6
	2,00	2x2	2x3	2x4	2x5	2x6
	1,50	1,5x2	1,5x3	1,5x4	1,5x5	1,5x6
	1,00	1x2				

USE Manning.xls (resources, eclass) with the GOAL SEEK tool.



Note: for the prism to be rectangular, z has to be set to zero.

PRESENT YOUR PROJECT IN A NICE WAY